Technical Workshop Report

Improving the Thermal Efficiency of Coal-Fired Power Plants in the United States

February 24-25, 2010

Sheraton Baltimore City Center
Baltimore, MD

Sponsored by:

Department of Energy and National Energy Technology Laboratory

Acknowledgements

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Executive Summary

The United States is entering an era of unprecedented change in the way we produce and use energy. The conventional thinking about how energy is extracted, converted, and consumed is being challenged by growing concerns about the environmental impacts of power generation on land, water, air quality, and climate. Although the long-term opportunity to reshape our energy infrastructure is promising, the current reality is that fossil energy remains the backbone of the Nation's energy economy. Currently, about half of our electricity is generated by coal-fired plants, which are also responsible for more than 80% of carbon emissions from the power sector. A comprehensive carbon management strategy should both address ways to reduce emissions through a change in the fundamental energy supply structure—which will take significant time—and simultaneously improve the performance of the existing infrastructure in the interim. One such option to improve the existing energy infrastructure is to increase the thermal efficiency of existing coal-fired power plants, which can achieve near-term and sustainable reductions in greenhouse gas and other environmentally damaging emissions.

The U.S. Department of Energy (DOE) has put forth a vision for reducing carbon emissions from existing power plants: **increase the overall thermal efficiency of the U.S. fleet of coal-fired power plants from 32.5% to 36% by 2020**. When power plant efficiency is increased, less coal is burned to produce the same amount of electricity, thereby avoiding the associated CO_2 and other emissions. Increasing overall fleet efficiency to 36% would save roughly 175 million metric tons (MMT) of greenhouse gases per year. Most important, these reductions can be sustained in future years, provided that good operating and maintenance practices continue.

Although the DOE vision is bold, 36% average fleet efficiency represents a carbon reduction opportunity that is substantial, economically and technically feasible, and near term. The current thermal efficiency of the roughly 900 U.S. coal-fired power plants varies significantly, from 27% for the lowest decile of the fleet to more than 37% for the highest decile. While the efficiency of a given facility is affected by the heating value of the coal, the type of boiler system, emissions control equipment, and other factors, data analysis of plant performance indicates that opportunities to increase efficiency exist across the entire fleet. Yet there is no silver bullet for achieving the 36% efficiency vision. It will require a variety of strategies that include: 1) widely adopting the practices and technologies used in the best performing plants, 2) challenging the best performing plants to seek additional efficiency improvements, and 3) retiring poorly performing plants where improvements are not technically or economically feasible.

Broad improvement in power plant efficiency will not happen without the combined leadership of industry and government. The private sector, which owns and operates most coal-fired plants, has the technical expertise and business acumen to identify and implement efficiency opportunities, while the government can help facilitate collaborative dialogue and provide technical analysis that can support national initiatives to achieve the efficiency vision. Toward this end, DOE and the National Energy Technology Laboratory (NETL) sponsored an industry workshop on February 25-26, 2010, in Baltimore, MD, designed to:

- Explore technical opportunities to improve the thermal efficiency of existing coal-fired power plants,
- Identify the barriers and challenges that inhibit implementation of these opportunities, and
- Identify specific initiatives that can substantially increase efficiency across the fleet.

The workshop built on a previous meeting held on July 15-16, 2009, in Chicago, IL, that provided an excellent foundation for this topic.[1] The Baltimore workshop reached out to a larger community and brought together 53 leading industry experts, utility owners and operators, equipment vendors, energy consultants, power industry associations, and research organizations to explore this topic.

Major Findings

Detailed workshop results from each of the three parallel work groups are provided in the following sections. Key findings and themes highlighted below are drawn from these results and from discussions during the plenary sessions.

- **Broad array of technical opportunities exist to improve thermal efficiency.**
  - Workshop participants identified a robust portfolio of more than 50 distinct opportunities to improve thermal efficiency, many of which can be applied broadly across most of the fleet of coal-fired power plants.
  - Numerous opportunities to improve efficiency can be found in new and improved processes; better sensing, measurement, and control; tighter operating procedures; better and more frequent maintenance; improved fuel handling; and capital upgrades and improvements (see box).
- **Power plant efficiency is not easily measured.**
  - The heat rate of a coal-fired power plant is not an essential performance metric for most utilities and is costly and difficult to accurately measure in real time. As a solid fuel, coal is not easy to measure in real-time; may be subject to variation in fuel quality; and may require costly equipment and engineering talent. Flow measurement of a solid fuel is a technical challenge that can have a very high margin of error.
  - Measuring CO_2/MWh may be the best available proxy for efficiency but better measures are needed.
  - Better national data on plant efficiency is needed, but this is hindered by the variation in methods and accuracy for measuring plant heat rate.
  - Without adequate heat rate data, it will be difficult to monitor improvements in the overall efficiency of the U.S. fleet of coal-fired power plants.

Key Technical Opportunities to Increase Thermal Efficiency

- Identify, implement, and train workers in best practices
- Incentivize best operators or employ a dedicated plant efficiency engineer
- Optimize processes using advanced computational tools
- Conduct on-line, real-time performance monitoring of efficiency
- Standardize performance metrics
- Reduce air, water, steam, and flue gas leakage
- Replace seals on air heaters, condensers, boilers, and tube components
- Upgrade turbines, including dense pack turbines, increased exhaust areas, and redesigned seals
- Use variable speed motors
- Lower stack temperature
- Use low-grade heat for coal drying
- Use flue gas condensing heat exchangers
- Implement intelligent soot blowing systems

[1] See http://www.netl.doe.gov/energy-analyses/pubs/NETL%20Power%20Plant%20Efficiency%20Workshop%20Report%20Final.pdf for the Chicago workshop report.

- **There is little financial incentive for utilities to improve their thermal efficiency.**
    - The need for high availability, high reliability, and low operating and maintenance (O&M) costs trumps efficiency every time.
    - Many utilities have rate clauses that pass fuel costs through to consumers. This takes away the financial incentive for utilities to reduce fuel costs.
    - Capital investments to improve thermal efficiency must compete with non-optional investments for environmental compliance or other energy projects that may offer higher returns on investment.
- **New thinking is needed on the role of coal-fired power plants.**
    - Public perception of coal power as inherently dirty may inhibit efficiency initiatives. An efficiency improvement at a coal-fired power plant ought to be viewed on equal footing with other clean power sources such as solar, wind, biomass, and nuclear.
    - The increase in intermittent, renewable-based power generation in the electric grid is changing the traditional baseload role of coal-fired power plants. Redefining the role of coal plants as an enabler for renewable energy may change both the public perception and economics of coal-fired generation.
    - Owners and operators of coal-fired power plants need to rethink the role of efficiency in plant operations and the climate debate. Management resistance to change is seen as a major inhibitor to improved thermal efficiency.
- **Efficiency improvements can be risky to operators.**
    - Any unplanned outage or extended plant downtime to accommodate an efficiency project has the potential to erase any fuel cost savings achieved. However, some improvements such as adding sensors or supplemental controls can be easily accommodated during normal outages. Technical uncertainty of projects needs to be minimized to ensure there will be no unexpected disruptions to power production.
    - Capital projects that have the potential to trigger a New Source Review are deemed to be very risky. Better clarity, and potentially guarantees, are needed on what upgrades will not trigger NSR.
    - Vagaries of each site prevent vendors from being able to guarantee results.
    - Uncertainty regarding future climate legislation/regulation may inhibit current efficiency projects because plant emission levels could be baselined after improvements are made, thereby penalizing utilities that proactively pursue efficiency improvements.
- **The power industry is unlikely to champion a national efficiency initiative.**
    - Although representatives from utilities and vendors are knowledgeable about efficiency improvements, it is not a management priority. Reduction in staff, shrinking O&M budgets, and limited access to capital will make it difficult for owners and operators to take on ambitious efficiency projects.
    - Power producers may view coal plants as cash cows to fund excursions into other power options including nuclear, renewable, and smart grid.
    - Both Federal and State level leadership, support, and incentives will be needed to enable the power industry to achieve the 36% efficiency vision.

Next Steps

Workshop participants did more than just identify opportunities for and challenges to improving thermal efficiency. They also developed an initial set of distinct initiatives that can be pursued by government and industry to put many of these promising ideas into action. In all, 11 initiatives were developed that describe the core concept, identify implementation steps, estimate benefits, clarify roles of government and industry, and outline next steps. While more work is needed, each of these initiatives, included in the sections that follow, represents the kernel of a new idea to increase efficiency and reduce carbon emissions.

DOE plans to use the results of the Baltimore and Chicago workshops, ongoing technical analysis of efficiency opportunities within the coal-fired fleet, and additional studies to develop a comprehensive strategy for capitalizing on thermal efficiency improvements.

How to Read This Report

The results that follow are based on the collective insights of workshop participants that were generated during breakout group discussions. Each of the three breakout groups was given the following tasks:

- Explore technical opportunities to improve the thermal efficiency of existing coal-fired power plants,
- Identify the barriers and challenges that inhibit implementation of these opportunities, and
- Identify specific initiatives that can substantially increase efficiency across the fleet.

The content of the text and tables that follow is based on the contribution of individual participants and do not necessarily represent a consensus view of the group. The facilitators encouraged open dialogue and systematically documented ideas and insights without attribution. Participants were given an opportunity to identify: (a) the **technical options** he or she felt would have the highest impact on power plant efficiency and be the most applicable across all coal-fired power plants; and (b) which **barriers & challenges** and **potential initiatives** were most important (see tables below for details). Options that received broad agreement within each breakout group are highlighted in the narrative of the three Summary Results sections that follow.

Summary Results—Group A

Participants

Scott Affelt	Zolo Technologies, Inc.
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Thamarai P. Chelvan	Siemens Energy, Inc.
Tom Fogarty	PNT Energy
David Hopkinson	U.S. Department of Energy
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Facilitators

Jack Eisenhauer and Lindsay Kishter

Technical Options to Increase Thermal Efficiency

Plant operators can implement a robust variety of currently available, cost-effective solutions to improve plant heat rate through improved processes, tighter operations, and better and more targeted maintenance. With sufficient capital, an even larger toolbox is available to enable efficiency improvements. Key technical options available include the following:

- Training a fleet of the plant's workers to identify inefficiencies and recognize opportunities for improvement will have a large impact and will help utilities to prioritize thermal efficiency options. Better yet, a dedicated plant efficiency engineer will reduce the burden on other workers and speed efficiency improvements.
- Reducing leakage in the air, water, steam, and flue gas flows by restoring and replacing seals offers one of the most promising opportunities for improved efficiency.
- Without major capital, process optimization across the plant can offer significant efficiency improvements. Improving a plant's ability to measure, monitor, and analyze system processes will enable plant operators to identify opportunities for efficiency improvements or maintenance needs that would prevent degradation and future inefficiencies. Implementing advanced sensors and controls will yield this valuable information and provide opportunities for improvement. However, uniform, reliable measurement processes and standards that are supported by adequate tools are not yet available to support real-time monitoring of plant heat rate.
- Operational improvements also present opportunities to increase efficiency. Better air handling through waste heat optimization and better fuel handling, such as increasing coal fineness, are key examples.
- As efficiency will always be dictated by the plant's existing equipment, the biggest potential gains can come from upgrading major systems. Upgrading the turbine systems by replacing blades and seals and upgrading the steam system through a major retrofit of boilers would have a significant impact on plant efficiency.

Barriers to Implementation of Technical Options

Plant owners are faced with various technical, regulatory, and market constraints that inhibit the adoption of technical solutions to boost efficiency. For example, energy efficiency is often not a priority for baseload coal plants and is not imbedded in the corporate culture. The costs, risks, and payoffs of efficiency improvements can be uncertain, further discouraging investment. Key barriers to the implementation of technical options include the following:

- Power plant efficiency projects lack the incentives, subsidies, and overarching political and public support that clean and renewable energy initiatives have enjoyed in recent legislation, including the American Recovery and Reinvestment Act. Without a government mandate for efficiency improvements and associated financial incentives, it is difficult for managers to invest scare capital in efficiency upgrades. Efficiency initiatives may not offer better payback than competing plant projects, yet may be deemed more risky and disruptive to operations.
- Plant operators often lack sufficient monitoring tools or measurement frameworks to measure both baselines and future improvements for a given process. Without advanced sensors and monitoring tools, operators find it difficult to accurately measure current processes, identify specific areas where upgrades could improve efficiency, and measure and communicate progress. The industry also lacks clear guidelines and standards for measuring and reporting efficiency improvements.
- With the possibility of CO_2 regulations and the development of a national energy policy on the horizon, plant owners may face requirements in the near term, yet they currently have little certainty about what those future requirements might be. Because of this, owners are hesitant to invest in efficiency projects that may not be economically prudent once new requirements come into effect. Owners are also hesitant to make large-scale, costly efficiency improvements that could then be set as a baseline in near-term legislation, effectively penalizing proactive plants.
- Uncertainty about making plant changes that might trigger a New Source Review has hampered some efficiency initiatives. Utilities often err on the side of caution when interpreting the NSR regulations and avoid certain efficiency projects with the belief that they may have their permits called into question.
- Every plant's top operational concerns are availability and reliability, and the top regulatory concern is environmental compliance; efficiency is a secondary concern. As such, most plants, especially smaller ones, do not have dedicated performance engineers trained to identify opportunities for efficiency improvements and implement upgrades.

Proposed Initiatives

Breakout Group A selected four initiatives that government and industry could implement in the short term to address the major barriers.

Federally Supported Certified Performance Engineer

Having a dedicated, on-site performance engineer will enable each facility to focus on improving thermal efficiency and fully exploit the range of technical options available to the facility. Currently, there is little incentive to invest in such a position because fuel costs savings rarely benefit the utility due to utility rate structures. This initiative creates a monetary incentive for utilities to cover the cost of a certified performance engineer while passing energy cost savings on to the ratepayers.

Understanding Efficiency Gains Triggered by Carbon Taxes

A carbon tax would likely trigger efficiency projects at coal-fired power plants, but there is little evidence about what types of efficiency gains would be realized at different carbon prices. This initiative seeks to better understand the expected efficiency gains at various carbon prices through comprehensive analysis using real plant data. The analysis would provide the necessary information to policymakers to make informed choices. This initiative proposes a study that builds on response-curve analysis at individual utilities to better calculate the efficiency gains that carbon taxes would likely trigger across the fleet.

Create Certainty Around CO_2 Baseline and BACT

This initiative establishes permit certainty for plant owners who enter a voluntary agreement in which they commit to efficiency improvements. Participating plants will work with government agencies to determine their CO_2 baseline and establish energy efficiency as the best available current technology (BACT). Plants will agree to meet an efficiency improvement from the established baseline.

Develop a Framework for Measuring and Sustaining Improvements

Establishing a framework for accurately measuring efficiency improvements and mandating that the performance data is shared on a national level creates indirect competition among plants and provides an incentive for thermal efficiency improvements. This initiative sets a standard for measuring both baseline and actual performance (in order to calculate the difference), and develops a clear guideline for best process optimization that gives plant owners rational expected targets for efficiency improvements.

Raw Results—Group A

GROUP A

Technical Options to Improve the Thermal Efficiency of Existing PC Power Plants (1 of 2)

<table>
<tr><th>Process</th><th>Operations</th><th>Maintenance</th></tr>
<tr>
<td>

Training workers in best practices ●●●●●●●
Process optimization ●●●●●●●
Improve information and monitoring of performance ●●●●●
Employ dedicated plant efficiency engineer ●●●●
Implementation of advanced sensors and controls ●●●
Tuning of all controls (measure correct) ●●
Cycle optimization ●
Steam cycle - adjustments in extraction flows, monitoring is part of good preventive maintenance
Analytics to reveal heat rate deviations in real-time ●
Load cycling start up and ramping controls
Steam cycle isolation
For boiler efficiency use latest PTC 4 not PTC 4.1
Firing system - balancing burners, system optimization and reducing turbine filter
Boiler water blow down recovery

</td>
<td>

Reduce flue gas exit temperature and use heat to pre-heat boiler ●●●
Improve soot blowing equipment ●●●
Optimize plant operation to match fuel quality and provide consistency ●●
Increase coal fineness to minimize unburned carbon ●●
Automated boiler drains ●
Get down to one compressor (to reduce leakage) ●
Use only one circulating water pump
Instrumentation calibration
Sliding pressure on boiler
Reduce excess air
Improve steam temperature control to operate at optimum temperature and reduce degradation
Increase hydrogen purity
Fuel switch
Water chemistry
Raise boiler temperature

</td>
<td>

Air, water, steam, flue gas leakage reduction ●●●●●●●
Reduce air heater leakages with better seals ●●●●
Increasing maintenance to arrest degradation ●
PDM programs (maintenance)
Restoring turbine seals
Ultrasonic checking around the compressor
Eliminate boiler air infiltration
Removing/preventing deposits on turbine blades
Cooling tower fill replacement

</td>
</tr>
</table>

● Best non-capital
▲ Best with capital

GROUP A

Technical Options to Improve the Thermal Efficiency of Existing PC Power Plants (2 of 2)

Capital	Major Capital	Serious Capital
• Optimize regenerative air heater or air pre-heater and 'right size' replacements (+ density) ▲ – Improves efficiency, increases air temperature, reduces leakages • Deep lake water intake rather than surface water • Lighting upgrades • Condenser upgrades: re-tubing condensers, circulating water strainers, condenser cleaning • Add cooling tower capacity – Lowers back pressure, allows you to generate more power • Material coatings on gas side • Replacement of older environmental controls with newer more efficient ones • Power supply upgrades and precipitators • Mill upgrades • Partial arc emission (steam) to reduce throttling losses • Advanced material upgrades on steam side to increase temperature	• Upgrade turbines ▲▲▲▲▲▲ – Replacing blades, seals • Pre-dry/pre-beneficiation of coal ▲▲ • Low pressure steam sales to nearest industry – Site specific and steam quality specific • Using solar energy for feed water heaters • Circulating water discharge turbine • Condensing heat exchangers • Exhaust hood steam guides to direct flow of steam and cut losses • Adjustable speed drives for large motors	• Repowering (major retrofit of boilers) ▲▲ – Going from sub- to super-critical adding O_2 instead of air, putting in gasifier, adding solar, etc. • Hot wind box with gas turbine (gas turbine exhausting into wind box) • Redesign heat transfer pressure parts – By boiler manufacturer or 3rd party • Retrofit with oxy-fuel combustion in place of air-fuel combustion

● Best non-capital
▲ Best with capital

GROUP A

Barriers and Challenges That Inhibit the Adoption and Application of Technical Options (1 of 2)

Technical Constraints	Costs and Payoffs	Regulatory and Market Constraints

• Difficult to accurately measure improvements ●●●●●
• Lack of information or data to make a decision
• Design constraints of existing equipment
• Unit age limits options
• Many solutions are not applicable across all plants
• Auxiliary power that has been added because of air quality control
	• Competing projects may have better payback (hurdle rate) ●●●●
	• Scarce availability of capital limits investments ●●●●
	• Managers don't get good return for efficiency investments ●●
	• Uncertainty around the costs and benefits of a given proposal ●
	  – Especially 1st-of-a-kind or 2nd-of-a-kind
	• Capacity factor
	• Budget for required environmental compliance reduces budgets available for efficiency improvement
		• Lack incentives/subsidy/support for generation efficiency ●●●●
		• Uncertainty about CO_2 regulations (what and when) ●●●
		  – avoid baseline after improvements are made
		• Possibility (uncertainty) about a national energy policy ●●●
		• Future role of the plant: baseload, backstop, etc. ●●
		• Energy price uncertainty that affects the cost/benefit of a project ●
		• Uncertainty about recovering capital cost for regulated company
		• No requirement for efficiency improvements from government agencies
		• Fuel switch in reverse - hard to go back
		• Fuel adjustment cost
		• NSR

● Most important

GROUP A

Barriers and Challenges that Inhibit the Adoption and Application of Technical Options (2 of 2)

Management Priorities/Corporate Culture	Knowledge and Training of Plant Employees	Common Perceptions
• Focus on availability and reliability instead of efficiency ● • Focus on bottom line rather than long term ● • Frequency of outages and time between outages (6 years between) • Company culture not conducive to efficiency • Following usual procedure rather than new approaches • Short planned outage time for making improvements • Lack of support from internal organization • Mentality of 'cheap, short term' rather than 'long term'	• Lack of training of plant operators and performance engineers ●● • No dedicated trained individual to implement improvements – Not having enough people to install • Lack of knowledge of smaller things plants can improve that do not require major capital	• Public perceptions about plant life expectancy • Generation efficiency is not seen as being on par with renewables within the public and government • Perceived notion of what will trigger a New Source Review – Fear that all permits called into question

● Most important

GROUP A

Potential Initiatives

- Framework for sustaining (and measuring) improvements
  - Fund a research program to develop standards for accurately measuring energy efficiency
  - Develop clear industry standards for best process optimization
  - Make more heat rate data available on the national level
- Provide future permit certainty if plants agree to meet an efficiency standard
- Fund federal performance engineer certification
- Develop training program in best practices for plant operators and maintenance
- Understand which efficiency projects are triggered by various levels of carbon taxes
- Engage state PUCs in discussions about greater use of price caps or shared savings regulation
- Improve transmission system to enable the retirement of older, inefficient units
- Treat generation efficiency the same as renewables, demand side management, other alternatives for stimulus funding and energy portfolio
- Make capital available by providing 0% loans for power plant efficiency projects
- Provide tax credit to fix hurdle rate
- Offer tax incentives for measurable efficiency improvements
- Demystify role of coal
- Pre-approve projects that <u>do not</u> trigger NSR, (example: turbine upgrade does not raise emissions)

GROUP A
Initiatives (1 of 4)

Federally Supported Certified Performance Engineer

Description and Key Features

Having a dedicated, on-site performance engineer will enable each facility to focus on improving thermal efficiency and fully exploit the range of technical options available to the facility. Currently, there is little incentive to invest in such a position because fuel costs savings rarely benefit the utility due to utility rate structures. This initiative creates a monetary incentive for utilities to cover the cost of a certified performance engineer while passing energy cost savings on to the ratepayers.

- Focuses attention on efficiency improvement
- States may be impressed at rate time which will be an advantage
- Performance engineer follows some best practice guidelines
- Some accounting for time will be needed
- Can be implemented with or without verification of heat rate improvement
- Focus on improvement then sustainment
- Need to avoid the performance engineer focusing on maintenance
- Green job creation
- $ savings passed to rate payers but monetary incentive goes to utility
- Activity-based performance

Implementation Steps

- Create requirements for program
  - Best practices items/checklist
- Provide training and certification
- Monitor and report heat rate
- Annual conference of engineers
- Annual certification/sanity check
- Work toward verification of heat rate improvements

Roles for Government

- Make funding/incentive available
- Develop requirements for certification
- Host annual conference

Roles for Industry/Others

- Verifying body—third party
- Plants
  - Participate
  - Collect data & report
  - Implementation

Estimated Impact (Metrics)

- Up to 1% improvement per plant (unit)
- 1% @ 500 MW ~ $0.5m savings
- Target the 300 stations with a unit > 150MW
- High uptake expected

Next Steps

- Identify the type of incentive needed
  - Discuss with plants
  - What is the best “delivery” mechanism

GROUP A

Initiatives (2 of 4)

<table>
<tr><th colspan="2">Understanding Efficiency Gains Triggered by Carbon Taxes</th></tr>
<tr><th colspan="2">Description and Key Features</th></tr>
<tr><td colspan="2">A carbon tax would likely trigger efficiency projects at coal-fired power plants, but there is little evidence about what types of efficiency gains would be realized at different carbon prices. This initiative seeks to better understand the expected efficiency gains at various carbon prices through comprehensive analysis using real plant data. The analysis would provide the necessary information to policymakers to make informed choices. This initiative proposes a study that builds on response-curve analysis at individual utilities to better calculate the efficiency gains that carbon taxes would likely trigger across the fleet.
• Built on real plant data and extends existing EPRI work
• Requires credibility and transparency</td></tr>
<tr><th colspan="2">Implementation Steps</th></tr>
<tr><td colspan="2">• Build on EPRI's response-curve analysis at individual utilities
• Hire people to help implement and maintain consistency
• Build aggregate response curve
• Plug results into ICF or other model to understand macro effects
• Understand "enablers"
• Build the case for policy audience
• Communicate analysis</td></tr>
<tr><th>Roles for Government</th><th>Roles for Industry/Others</th></tr>
<tr><td>• Cost share analysis
• Manage/champion the effort
• Fund team of efficiency experts to go into plants
• Communicate information (possibly EPRI)</td><td>• Utilities would participate in measuring plant information—develop budget for gathering data
• Vendors provide cost information to help guide project cost/benefit</td></tr>
<tr><th>Estimated Impact (Metrics)</th><th>Next Steps</th></tr>
<tr><td>• No direct impact
• Inform decisions about carbon taxes
• Shows benefit at various $/ton</td><td>• Work with EPRI to create plant assessment guideline</td></tr>
</table>

GROUP A

INITIATIVES (3 OF 4)

Create Certainty Around CO_2 Baseline and BACT

Description and Key Features

This initiative establishes permit certainty for plant owners who enter a voluntary agreement in which they commit to efficiency improvements. Participating plants will work with government agencies to determine their CO_2 baseline and establish energy efficiency as the best available current technology (BACT). Plants will agree to meet an efficiency improvement from the established baseline.

- Plants are potentially still exposed to legislation, but this gets rid of some variables
- Plants receive positive public perception for acting early on efficiency improvements
- The definition of BACT = efficiency improvements
- Plants still subject to future cap and trade that might make future upgrades cost-effective
- Voluntary program—deal early and deal fast
- No legislation required

Implementation Steps

- Utility establishes efficiency program for the unit that promises an efficiency improvement off the baseline
  - ~2 years to implement—this step requires more accurate measurements, which could be achieved by enacting the initiative "Develop a Framework for Measuring and Sustaining Improvements"
- EPA sets baseline CO_2 and BACT

Roles for Government

- Figure out if this is legally feasible
- DOE and EPA work out agreement
- Determine what agency goals are; if goals are to shut down coal plants, they won't implement this program

Roles for Industry/Others

- Develop and submit efficiency programs for their units

Estimated Impact (Metrics)

- >50% will participate (conservative estimate)
- 1% improvement
  - If CO_2 reaches \$100/ton, maybe 5% improvement
  - If CO_2 reaches \$30/ton, 2% improvement

Next Steps

- DOE and EPA start discussions to see if there is a deal that can be made

Develop a Framework for Measuring and Sustaining Improvements

Description and Key Features

Establishing a framework for accurately measuring efficiency improvements and mandating that the performance data is shared on a national level creates indirect competition among plants and provides an incentive for thermal efficiency improvements. This initiative sets a standard for measuring both baseline and actual performance (in order to calculate the difference), and develops a clear guideline for best process optimization that gives plant owners rational expected targets for efficiency improvements.

- Gives plant owners a basis to compare their plant to other plants
- Enables capability to discover the source of inefficiencies at a general level
- Delivers a best practice for how to optimize

Implementation Steps

- Take PTC4.1 as a basis and refine, then develop protocol to continually update baseline to as-is conditions
- Develop clear guideline/calculation framework for best process optimization, establishing rational expected targets for plant
- Establish means to share performance information on a national level

Roles for Government	Roles for Industry/Others
• Mandate that data is collected and reported • Set up and drive program	• Help develop protocols • Use framework to collect and report data

Estimated Impact (Metrics)	Next Steps
• Enabler of efficiency improvements • Greater awareness of national performance data creates indirect competition and incentive for improvements	• Take interested individuals from industry and government to develop working groups and begin work on protocols • Better define roles • Find money to fund the program

Summary Results—Group B

Participants

Ron Breault	National Energy Technology Laboratory
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Stan Kaplan	Congressional Research Service
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Sherry Odom	GE Energy
William Pott	Booz Allen Hamilton
Darlene Radcliffe	Duke Energy
Donald E. Ryan	The Babcock & Wilcox Company
Bob Seay	Worley Parsons Group, Inc.
Jeff Stallings	Electric Power Research Institute

Facilitators

Ross Brindle and Amanda Greene

Technical Options to Increase Thermal Efficiency

Broad opportunities for efficiency improvements exist, including operations management, maintenance, new technologies, fuel issues, measurements and controls, process improvements and capital equipment upgrades, and human factors. Approximately half of the recommendations involve technical improvements that require capital expenditures and/or investment in some level of R&D. Options that would provide the highest value include the following:

- There is an urgent need for technology that can conduct on-line real-time measurement of efficiency. Because an accurate real-time measurement of heat rate is very difficult and expensive, it may require the development of a new standard efficiency metric, such as CO_2/MWh (instead of heat rate), which will not only allow for real-time tracking of efficiency within a coal plant, but will enable efficiency comparisons among different coal plants and across different power generation technologies.
- Upgrading power plant equipment is needed to reclaim some of the efficiency losses associated with aging power plants. Steam turbine upgrade packages in particular (e.g., dense pack turbines, increased exhaust areas, seal redesigns) can provide significant efficiency improvements. Also highly recommended is installing variable speed motors and acquiring equipment that can help lower stack temperatures, such as plastic heat exchangers.
- There is significant potential for modeling software to contribute to efficiency improvements in power plants. For example, 3-D modeling of the burner/boiler process could help to reduce unburned carbon loss and balance the air flow and burn of firing. There is also a need for the development and use of neural networks optimization scheme software. Process optimization, in addition to being performed for individual units, could be done at a higher level, taking into consideration the inter-relations across different environmental control systems.

- Large quantities of heat are wasted at power plants and there is an opportunity to improve heat recovery. While some amount of heat loss is inevitable, much of the heat could be recovered for additional power and heat for plant operations as and/or for district heating.

Less technical options, such as behavioral and functional changes among staff and improvements in day-to-day operations and maintenance procedures requiring less capital investments, also present promising efficiency improvements:

- Proper maintenance practices such as replacing seals on all unit operations and cleaning condenser tubes will help to reclaim the natural efficiency losses that occur in power plants as they age and components degrade. Additionally, regular maintenance should be performed to calibrate instrumentation, reduce steam leaks, and minimize condenser back pressure.
- Properly trained and incentivized staff is essential for efficient plant operations. In addition to hiring well-trained performance engineers, it is critical to create incentives for current operator teams to achieve heat-rate targets. Power plant operations would particularly benefit from the creation of a "heat-rate champion" role at the corporate level.
- Optimizing the fuel quality to reduce the moisture content of fuel is another relatively simple and cost-effective way to improve combustion efficiency at coal-fired power plants.

The majority of the high-value solutions listed above were also deemed to be applicable across a wide range of plants, with the exception of improved fuel management practices.

Barriers to Implementation of Technical Options

Numerous barriers to implementing thermal efficiency improvements in coal-fired power plants exist. The majority, however, directly or indirectly relate to the lack of a business case (from the perspective of power plant owners) for both capital investments in efficiency improvements and the implementation of operational changes that go along with new technology and new processes. Key barriers that contribute to this issue, including lack of business incentives, uncertain policies, technology risk, and organizational issues, are detailed below:

- Economic incentives for coal power plant owners and operators to improve efficiency are lacking. What business case does exist for efficiency improvements is counteracted by prevalent financial disincentives.
  - The power market rewards power generators for availability and reliability, not efficiency.
  - Currently, many utilities pass 100% of the fuel costs (or savings) to consumers, giving operators little incentive to reduce fuel costs.
  - The payback time required by regulated utilities is short, which prevents longer-term investments from being made and precludes risk-taking by owner/operators.
  - There are uncertainties surrounding whether capital investments will be allowed into the rate base and about the requirements for full commitment guarantees by banks.
  - Power production does not capture all costs externalities associated with the high carbon content of coal.
- The power sector currently receives mixed and confusing policy signals. In such an uncertain policy environment, owner/operators find it difficult to predict regulations and face the possibility that making efficiency improvements could provoke further regulation. This results in increased risk for making improvements.
  - Different definitions and valuations of CO_2 reductions appear to be inconsistent among energy sources.

- Clean energy programs do not recognize or reward efficiency improvements from coal plants; efficiency incentives (e.g., tax credits) that do exist focus on consumers, not power generators.
    - New Source Review triggers are often unclear, and the outcomes can vary under different administrations, by regional offices, and by the particular court hearing the case.
- It is difficult to make a business case for adopting new technology when the efficiency gains are hard to measure (industry does not use CO_2/MWh as a measure of efficiency). This contributes to uncertainties in the relative benefits and costs of new technologies as well as unexpected impacts and consequences.
    - There is little understanding of the side effects and potential risks of technology upgrades, including operational, environmental, and safety-related impacts. Sales people from vendor companies are often not technical experts and do not understand the risks and costs themselves. This can result in hidden costs for owner/operators when implementing new technologies.
- Even when efficiency improvements are cost-effective (or potentially so), they can be difficult to implement due to internal operational and human resource limitations.
    - There is a lack of engineering talent to evaluate each plant before choosing which options to pursue, and a lack of time and resources to carry out efficiency projects.
    - Some operators are resistant to any change, whether it is a new technology or a new person (e.g., heat-rate champion).
    - Heat rate projects have historically been unsustainable. Heat rate has a bad connotation among plant managers, partly due to the difficulty in measuring it.
    - There is a historic lack of consistency among leadership at utilities who often do not have a technical understanding of the plant and have short-term views.

Two additional types of barriers were identified that, although they also impact owner/operators and their decision to make efficiency improvements, can be viewed as issues more closely associated with the technology supplier (upstream) and end-use customer (downstream) parts of the energy sector supply chain.

- Commercialization challenges are faced by vendors and manufacturers of new technology, which inhibits or delays its availability to owner/operators.
    - The current technology RD&D path does not provide enough support for start-up companies, vendors and manufacturers of new efficiency technologies to go to market on large scales (i.e., 5–50 MW demonstrations). The government often funds to a certain point in the technology development pathway and then stops. Great technologies die because of this "technology deployment abyss."
    - Technology suppliers often get squeezed in federally funded demonstration projects. Government cost shares to support technology development are granted to the utilities, who in turn expect the supplier to give full commercial guarantees for these new technologies.
- Public perceptions and misperceptions further exacerbate the challenges of incentivizing the efficiency improvements discussed above and, in particular, inhibits beneficial policy changes.
    - There is strong consumer resistance to increases in power prices.
    - There is a lack of education among the public about the carbon reduction parity concept, leading to a bias towards CO_2 reductions from renewables over reductions from power plant efficiency improvements.

Proposed Initiatives

Create Common and Accurate Definition and Standard for Measuring Efficiency in Real Time

A well-defined efficiency metric will enable the achievement of real-time efficiency measurements, and will help to address inconsistent and confusing national and state policies on carbon reduction and clean energy. Currently there is no consistent standard for measuring thermal efficiency. Technologies exist today for measuring heat rate, but they are expensive, require human resources to continually monitor them, and only measure surface attributes. In addition to enabling real-time monitoring, the standardized efficiency metric should be developed to allow thermal efficiency improvements in coal plants to be compared to other power generation technologies. This will help pave the way for such efficiency improvements to qualify under federal and state clean energy/low-carbon incentive programs.

Incentivize Industry to Pursue Efficiency Improvements

The overarching challenge to implementing efficiency improvements in coal plants is the lack of a business case for owner/operators of power plants. Building a business case for industry is broad initiative and involves a myriad of potential actions on the path towards its achievement. Two major features include:

- The inclusion of externalities in financial decisions through, for example, a price on carbon (e.g. carbon tax, cap and trade program); parity between efficiency improvements and other clean energy technology under RPS and/or other carbon reduction policies; and the education of the public that a pound of CO_2 reduced is a pound of CO_2 reduced, no matter what the source.
- Making changes to federal and state regulations such that costs and savings (e.g., fuel costs) are shared between utilities and consumers (instead of passing 100% through to consumer).

Education and Promotion of Generation Efficiency

The public does not currently value carbon reductions from efficiency improvements in power plants the way it values the same reductions from, for example, solar and wind power. It is important for the public to understand that a pound of CO_2 reduced is a pound of CO_2 reduced, no matter where it comes from or how it is done. Educating the public will further push public policy toward treating efficiency improvements as an equally significant and beneficial option for reducing CO_2, which should receive the same incentives as other methods of reducing CO_2.

Raw Results—Group B

GROUP B

Technical Options to Improve the Thermal Efficiency of Existing PC Power Plants (1 of 2)

Operations management	New Technologies	Fuel Issues	Human Factors	Measurement and Controls
• Balance/optimize combustion process, including during ramping (e.g. balance air flow ● • Adhere to best practices with regards to operations and business planning • Avoid de-rating unit in evening to shed slag • Optimize and integrate across environmental control systems (not just in single unit) • Optimize dispatch to minimize ramping • Update dispatch data more regularly (>1-3 yrs); need real-time data. (Grid level improvement)	• Use solar thermal to improve feed-water heater • Add bottoming cycle (low temperature working fluids from geotherm coupled with exhaust from turbines; then take through another cycle)	• Reduce moisture content of fuel ● – Use condenser (waste heat) stream to dry fuel – Use flue gas upstream of scrubber • Optimize fuel (tight band to optimize boiler operation) ● – Buy different/better fuel – Blend – Dry fine (to reduce moisture content of fuel)	• Incentivize ($) operator team to achieve heat rate targets ●●●● ▲▲▲ • Assign a heat rate champion role (corporate responsibility) ●● • Hire adequately trained performance engineers ●● • Provide information flow from operator upward (corporate idea box upward) • Implement operator apprenticeships • Acquire needed efficiency to reach priority of uptime generation and availability/reliability	• Conduct on-line real-time measurement of efficiency ●●●●●●● ▲ – Online fuel analyzer to characterize fuel inputs at lower cost – Mainstream online coal monitoring (to detect type of coal) – Update/monitor controllable losses screens on control systems for operators use • Develop a CO_2/MWh efficiency standard/metric (instead of heat rate) ●

● Highest impact on efficiency
▲ Most widely applicable across all plants

GROUP B

Technical Options to Improve the Thermal Efficiency of Existing PC Power Plants (2of 2)

Maintenance	Process Improvements	Capital Equipment Upgrades

• Replace seals, e.g. on turbines, air heaters, condensers, boilers and tubular components ●●●●●
• Implement/apply best practices for maintenance (plant-specific improvement) ●●● ▲
• Minimize condenser back pressure ●●●
• Reduce steam leaks ●●
• Lower condenser temperature by cleaning condenser tubes annually ●●
• Maintain instrument calibration ●●
• Tighten up boiler casing to reduce air leakage
• Maximize use of predictive maintenance to avoid outages and de-rate events
• Conduct regular air heater maintenance
• Remove deposits on turbine blades
• Control mill performance
• Tune plant controls system
	• Perform combustion optimization (NCR application) 3D view of boiler process ●●● ▲▲
	• Develop neural networks optimization schemes software ●●●●
	• Improve operation during ramps ●●
	  – This is needed more with increased wind generation
	• Conduct burner/boiler modeling to reduce unburned carbon loss - CFD ●
	• Optimize combustion to eliminate slag formation and fouling
	• Create innovative soot blowing schemes
	• Develop standard control systems for feed water heater with DCA
	  – Drain cooler approach DCA
		• Use variable speed motors ●●●●●
		• Lower stack temperature●●●●●
		  – Change the way firing is done
		  – Install plastic heat exchanger right before hits stack (on clean gas side); when gas hits dew point.
		  – Undertake air heater modifications; improve/replace air heater seals.
		• Use steam turbine upgrade packages ●●●● ▲▲▲▲▲
		  – Dense pack turbines
		  – Increased exhaust areas
		  – Redesign seals
		• Convert plants to district heating AND power plants to use waste heat ●●● ▲
		  – Go from 30 to 90% efficient
		• Optimize the economizer surfaces with air heater surface and feed water heater
		• Use axial versus radial fan blades
		• Reduce over-sizing of equipment that is driven by reliability concerns
		• Reduce parasitics (FGD) - better distribution, lower pressure drops.
		• Upgrade feed water heater tubes
		• Reconfigure/replace cooling tower fill
		• Improve environmental control systems (SCR, FGD, ESP)
		• Re-tube boilers (that were designed for bituminous coal but are using today's coal) in order to rebalance radiant heat
		• Convert electric drive pumps and fans to steam driven pumps/fans.
		• Use sliding pressure control for load following.

● Highest impact on efficiency
▲ Most widely applicable across all plants

GROUP B

Barriers and Challenges That Inhibit the Adoption and Application of Technical Options (1 of 3)

Organizational and Cultural	Market Structure
• Lack of engineering talent needed to evaluate each plant before choosing which options to pursue ●●●●● – Where will teams come from? – Evaluation takes time, costs change from beginning to end – Not enough engineering resources available at national scale (changes made at plant scale) – Unable to harness the current engineering talent – There are technical challenges that require experts – Great engineers at utilities but ranks getting thin • Some operators resistant to change - new technology and new people ●● • Culture (inertia) resistance to change ●● – Even with incentives, change is slow • Lack of time and resources to address these issues ●● – Visible stress at plants – people that remain are over-worked – Workforce shrinkage, no excess capacity • Historical lack of sustainability of heat rate projects ●● – “Heat rate” has a bad connotation among plant managers – Hard to measure heat rate • Lack of consistency among leadership at utilities ● – Operating in silos – Short-term view – Non technical managers/leaders • Less trust between plant owners and vendors (than in Europe where power sector is regulated) • Operators are not engaged in implementation of neural networks - can get resistance from operators • Buyers buy coal on spot market without regard to operations – Mis-match on coal burned vs. design coal • Resistance in U.S. to lower stack temperature - fear of reaching acid dew point – Europe has broken through this fear • Gap between new/optimal technology and it taking root in the control room – Poor interface and access to optimization software for operators – Manageable at floor level • Old stories about why “we cannot do that” - legacy/memory	• Power production does not capture all costs (does not integrate externalities) ●●●●● – Fuel does not cost enough; no cost to carbon • Uncertainty that capital will be available and allowed into rate base ●● – Requirements for full commitment guarantees by banks – Raising capital difficult • Efficiency efforts focus on consumers (end users) – Utilities cannot make money (as end-users control demand side) • Distance between power and steam markets inhibits district heating • Not cost-effective (not financially justified or driven)*

*Fundamental barriers agreed to be top priorities, but not voted on.

● Most important

GROUP B

BARRIERS AND CHALLENGES THAT INHIBIT THE ADOPTION AND APPLICATION OF TECHNICAL OPTIONS (2 OF 3)

Incentives $	Consumer/Cultural

• Market does not pay utilities for efficiency ●●●●●●●●●●●
  – Market pays for reliability and availability, not efficiency
• There are financial (regulatory) disincentives that counter-balance the business case that does exist ●
  – Fuel cost pass through disincentive
• Other disincentives (even without fuel pass through) e.g., investment risk of installing and using new technology/equipment ●
  – Incentives in companies do not support risk taking
  – The coal buyer gets the bonus for efficiency improvements, not the operators/plant managers
  – Risk/reward equation is not right, benefits are not allocated to the risk taker
• Utilities often have very short-term payback requirements that prevent investment
• Installation costs (e.g., of seals) greater than the amount of money saved by decreasing outage time
  – Labor cost of installation of seals and outage cost too high
• Pressure to reduce non-fuel O&M costs (FTEs)
  – Deregulation and competition driving this
	• Public resistance to increases in power prices ●●●●●
	• Lack of public education about carbon reduction parity concept
	  – Public favors CO_2 reductions from wind, not those from coal efficiency

● Most important

GROUP B

BARRIERS AND CHALLENGES THAT INHIBIT THE ADOPTION AND APPLICATION OF TECHNICAL OPTIONS (3 OF 3)

Policy	Technology Risk	Lack of Commercial Structure
• Lack of parity under RPS schemes (ton CO2 from efficiency is not equivalent to a ton of CO2 from wind under RPS and other green energy incentive schemes) ●●●●●●● – Lack of commensurate incentives like those for renewables – No credit for unburned carbon • New Source Review (NSR)* – Uncertainty surrounding potentially triggering NSR – No fixed set of rules for how one can trigger NSR – Rules change under different administrations and between different regional offices – Outcomes depend on court – Courts favor EPA more times than not	• Hard to make a business case for something one cannot measure ●●●●●●● – Cannot measure efficiency (heat-rate) – Industry does not use CO_2/MWh as a measure of efficiency • Little understanding of side effects of technology upgrades ●● – Hidden costs – Dense pack turbines - seals will wear as dispatch profiles change – Lack of sharing of all costs – Utilities talk to vendors' sales people (not the technicians) who do not accurately describe technical aspects, risks, side effects and costs • Limited knowledge of costs/benefits of new technologies and associated changes • Uncertainty around coal drier emissions • Biomass burner/boiler feed is not designed for efficiency • Perceptions of fuel flammability after drying - real or perception • Drying coal is an environmental issue (volatiles and hydrocarbons) • Proposals for equipment/plants evaluated by efficiency, but once installed no one cares about efficiency anymore	• "Technology development/demonstration abyss" ●● – Government funds to certain point, then stops – New startup companies cannot bring product to scale (e.g. 5-50 MW demonstrations) – Great technologies die because of this abyss • Technology suppliers get squeezed in federally funded demonstration projects ● – Utilities that receive government cost share to support technology development expect supplier to give full commercial guarantees for these new technologies

*Fundamental barriers agreed to be top priorities, but not voted on.

● Most important

GROUP B

Potential Initiatives

Create Common and Accurate Definition and Standard for Measuring Efficiency in Real-Time	Education and Promotion of Importance of Generation efficiency	Accurately Incentivize Industry to Pursue Efficiency Improvements	Include Externalities in Financial Decision-making*
• CO_2 measurement • Continuous real-time, online testing procedure.	• Educate public that generation efficiency of coal is on par with wind in terms of CO_2 reductions (a pound of CO_2 saved is a pound of CO_2 saved regardless of where comes from) • Need clear signals from government • Clear messages to consumers	• State and Federal Government consider more savings sharing (e.g. fuel pass through) between utility and consumers	• RPS parity • Carbon price

**In the sub-group break-out sessions to development initiatives, the "Include Externalities…" initiative was determined to be a key feature of the "Accurately Incentivize Industry to Pursue Efficiency Improvements" initiative. Thus, they were merged into a single initiative.*

Common and Accurate Definition and Standard for Measuring Efficiency in Real Time

Description and Key Features

A well-defined efficiency metric will enable the achievement of real-time efficiency measurements, and will help to address inconsistent and confusing national and state policies on carbon reduction and clean energy. Currently there is no consistent standard for measuring thermal efficiency. Technologies exist today for measuring heat rate, but they are expensive, require human resources to continually monitor them, and only measure surface attributes. In addition to enabling real-time monitoring, the standardized efficiency metric should be developed to allow thermal efficiency improvements in coal plants to be compared to other power generation technologies. This will help pave the way for such efficiency improvements to qualify under federal and state clean energy/low-carbon incentive programs. Key attributes include:

- Accurate and precise
- Available soon
- Reasonable cost
- Relatively simple to run
- Possible use of CO_2/MWh as a metric, though this will require a big cultural change

Implementation Steps

- Go through standards groups (ASME, EPRI, NIST, utility organizations) to develop standards
- DOE facilitates discussions to express industry needs and government drivers
- DOE funds instrument(s) to do this better through NETL
- Explore whether this data should be among the set of standard data reported to NERC, EPRI, etc. (longer term, after the above accomplished)

Roles for Government	Roles for Industry/Others
• Facilitated discussions (DOE) • Technology development funding (DOE) • Reporting – extend EIA reporting of heat-rates (EIA form 860) to the new standard; publish data for baseline trend information.	• Support and participate in discussions; everyone should have a seat at the table • Ensure that discussions stay technical

Estimated Impact (Metrics)	Next Steps
• Existence of a consistent metric • Base for any efficiency gain is measured • Baseline set and consistent metric to use for comparisons across different technologies	• Compile existing research on this topic • Identify stakeholders who need to be at the table • Establish lead contractor to own this (it is not a volunteer effort)

Provide Incentives to Industry to Pursue Efficiency Improvements

Description and Key Features

The overarching challenge to implementing efficiency improvements in coal plants is the lack of a business case for owner/operators of power plants. Building a business case for industry is a broad initiative and involves a myriad of potential actions on the path toward its achievement. Two major features include:

- Inclusion of externalities in financial decisions through:
  - a price on carbon (e.g. carbon tax, cap and trade program)
  - parity between efficiency improvements and other clean energy technology under RPS and other carbon reduction programs
  - public education that a pound of CO_2 reduced is a pound of CO_2 reduced, no matter what the source
- Making changes to federal and state regulations such that costs and savings (e.g. fuel costs) are shared between utilities and consumers instead of passing 100% through to consumer.

Implementation Steps

- Evaluate efficiency improvement costs to reduce CO_2 at coal plants relative to alternative low-carbon technologies
- DOE publishes report on cost-effectiveness and CO_2 reduction potential of efficiency improvements
- Develop standardized unit of measurement for efficiency
- Establish unit of measurement for RPS (e.g. pound of CO_2/MWh reduced)
- Educate states through NERUC on RPS
- Analyze fuel pass through cost-sharing approach

Roles for Government

- Evaluation of costs of various CO_2 reduction technologies, including supply-side efficiency improvements
- Publication of report of cost-effectiveness of efficiency improvements
- Host stakeholder workshop on cost-sharing methodologies (fuel pass-through model)
- State governments pilot RPS parity

Roles for Industry/Others

- Possibilities include education of states and consumers sponsoring programs in schools, leveraging trade associations and council communication networks.

Estimated Impact (Metrics)

- Greater number of efficiency improvement projects.
- Parity of CO_2 reduction methods.
- Impacts of efforts might be measured by:
  - number of bills passed reflecting parity
  - polls reporting public acceptance
  - articles and media attention
  - number of states without 100% pass through to consumers
  - number of states that include supply-side efficiency in RPS programs

Next Steps

- DOE workshop with industry with respect to potential for achieving goal
- Workshop on public education strategy

GROUP B
INITIATIVES (3 OF 3)

<table>
<tr><th colspan="2">Education and Promotion of Generation Efficiency</th></tr>
<tr><th colspan="2">Description and Key Features</th></tr>
<tr><td colspan="2">The public does not currently value carbon reductions from efficiency improvements in power plants the way it values the same reductions from, for example, solar and wind power. It is important for the public to understand that a pound of CO_2 reduced is a pound of CO_2 reduced, no matter where it comes from or how it is done. Educating the public will further push public policy towards treating efficiency improvements as an equally significant and beneficial option for reducing CO_2, which should receive the same incentives as other methods of reducing CO_2.
• Key message – a pound of carbon saved is a pound of carbon saved, no matter where it comes from (e.g. wind generation, carbon sequestration, increased coal efficiency, etc.)</td></tr>
<tr><th colspan="2">Implementation Steps</th></tr>
<tr><td colspan="2">• Implementation will involve effectively conveying to law makers and the public the options for CO_2 reduction on a cost per ton of CO_2 basis.
• Specific steps TBD</td></tr>
<tr><th>Roles for Government</th><th>Roles for Industry/Others</th></tr>
<tr><td>• Dissemination of information
• Equate efficiency improvements (on generation supply side) to other low-carbon/green technologies</td><td>• Limited due to conflict of interest issues</td></tr>
<tr><th>Estimated Impact (Metrics)</th><th>Next Steps</th></tr>
<tr><td>• Parity of CO_2 reduction methods
• Educated populous</td><td>• TBD</td></tr>
</table>

Summary Results—Group C

Participants

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Facilitators

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Technical Options to Increase Thermal Efficiency

A promising toolkit of technologies and processes are available to plant owners and operators to improve thermal efficiency, including waste heat recovery, equipment modernization, better maintenance practices, improved monitoring, and improved fuel management. High-impact opportunities include the following:

- Large quantities of heat are wasted at power generation plants. Improvements to the management of waste heat, many of which are easily implementable, can lead to increased efficiency levels. Specific opportunities include the following:
    - Re-burn ash to obtain the greatest heat energy from fuel
    - Capture excess heat from vented steam for reuse
    - Install and maintain insulation of the turbine and other sites of heat radiation
- Many plants in the fleet are very old, and modernization of the equipment used in coal-fired power plants will be essential to achieve the desired increase in efficiency. Modeling could be a significant tool in this effort (e.g., the application of computational fluid dynamics). Another important option is to educate operators on the importance of component optimization and the minimization of redundancies of existing power plant systems. New and improved materials would allow for turbine upgrades, and operators would be able to implement more efficient operating temperatures and pressures throughout the steam path. For many plants, however, retirement may be a better option, particularly if voluntary retirement were to lead to the construction of a new and more efficient coal-fired plant.
- As turbines age and components degrade, there are natural losses in efficiency; better management of fouling presents a significant opportunity to reclaim these losses. In particular, improvements in soot blowing are an attractive opportunity, including the introduction of intelligent blowing systems, or the conversion of the air used in such a system to steam. Regular

and more thorough cleaning of the system represents a significant opportunity for efficiency gains.

- Improvements in monitoring systems would help increase plant efficiency. Of particular interest is the capability to obtain accurate measurements, in real time, and enable instant system adjustments to optimize plant operation and efficiency. Also, early detection of leaks, possibly through thermocouples or air flow measurements, would allow plant personnel to respond to problems more quickly and more effectively.
- Improved coal management practices can help boost efficiency. However, fuel concerns are not prominent among plant operators. Cost-effective improvements in the treatment of coal can be implemented with relative ease to increase overall efficiency; these improvements include using low-grade heat to dry, covering coal piles to keep them dry, and the prevention of loss of heat value through stagnation and degradation.

Barriers to Implementation of Technical Options

Cultural, market, and regulatory barriers represent the biggest challenges to owners/operators in making efficiency improvements. These barriers are detailed below:

- The existing operator culture—valuing plant reliability over efficiency—is a significant barrier to the implementation of technical options for efficiency improvements. Manager support for upgrades and maintenance that could positively impact efficiency is small.
    - Currently, plant operators purposefully introduce a large amount of redundancy in their systems to maintain peak reliability, significantly reducing the efficiency of power production.
    - Small staffing at most plants makes changes extremely difficult to implement. Operators at understaffed plants do not have the time or the financial resources to address problems outside the scope of their required activities.
- The lack of incentives for improvements further discourages efforts to increase efficiency. The capital cost required for equipment replacements can often be prohibitive, while the ability to pass increases in fuel costs to consumers removes the economic motivation to make those upgrades. Even with the drive to improve, the many challenges associated with obtaining capital funding make taking such action difficult; often, short-term needs prevent plants from embarking on efforts that would be beneficial in the long term.
    - Fear of triggering the New Source Review provision of the Clean Air Act prevents significant action from being taken.
- The uncertainty of future regulation is a major barrier to the implementation of plant improvements. The many scenarios associated with the introduction of new carbon emission regulations prevents plants from taking long-term action, particularly the possibility that new regulations and standards could invalidate improvements made.
    - Many in the coal industry find the visions of DOE and the EPA to be in conflict—that DOE wishes to increase the efficiency of coal-fired plants, whereas the EPA wishes to phase out coal-fired generation completely.

Proposed Initiatives

Technology Demonstrations

This initiative seeks to demonstrate and quantify the benefit of technologies that can increase efficiency. Successful implementation would require a team of experts to identify candidate technologies, determine metrics for assessment, and provide plants with both data and the opportunity to see the benefits of the technologies firsthand. Such a program not only boosts efficiency and benefits the plants, but may serve as the foundation for future investments in other plants.

Reach Out to Senior Management of Utilities

This initiative seeks to justify investment in heat-rate improvements to senior management utility personnel through non-economic motivation. Successful implementation would require very high-level involvement at a government level to capture the attention of utility CEOs, a PR campaign, and the establishment of a highly visible award for efficiency improvements. Such a program could fuel competition among utilities and achieve broad efficiency increases nationwide.

Incentives for Existing Fleet to Implement Upgrades/Repairs

This initiative seeks to provide incentives for the existing coal-fired fleet to implement equipment upgrades and/or repairs. Successful implementation would require the identification of particular improvement opportunities and incentives to be granted, as well as a standard for the determination of efficiency. This program would be applicable to plants of all sizes and efficiencies, would allow utilities to quantify improvements implemented by both dollar and CO_2 value, and would help enable coal-fired plants to accommodate carbon capture and storage.

Retire Plants with Heat Rate Above a Certain Level

This initiative seeks to quantify a heat-rate level above which power plants would be encouraged to retire (11,200 MMBtu/kWh was suggested). Successful implementation would require the adoption of a standard method for determining heat rate and subsequent application, as well the identification and proffering of the incentive(s) to do so. Such a program would remove the plants with the lowest efficiency and provide plant managers with an alternative to running their plants into the ground.

Raw Results—Group C

GROUP C

Technical Options to Improve the Thermal Efficiency of Existing PC Power Plants (1 of 2)

New Operating Practices	Equipment	Improved Operating Practices
• Centralized performance groups ●● ▲ • Automated system to examine/process incoming coal • Biomass co-fire separate fluid bed boiler • Calcinate limestone (or lime) in boiler to ease cleaning (need research)	• High or low pressure turbine upgrade ●●● ▲ • Flue gas (to heat condensate) condensing heat exchanger ●●●●● • Equipment (steam path) upgrades—CFD model ●●●●● • Intelligent soot blowing systems ●●●● • Variable speed drives ●●● • Combined heat and power ●●● • Increasing operating temperatures of boilers/turbines with new materials ● • Fan upgrades—axial fans ● • Investigate DC corona for backpressure reduction ● • Condenser ball cleaning system ● • Increase hydrogen purity—reduce cooling losses • Better boiler insulation to reduce heat radiation • Streamside condenser nano-coating • Facility best practices—LED lighting, etc. • Steam soot blowing (conversion from air to steam) • Organic Rankine cycle • Natural circulation boilers • Guardian and Vortex seals • Replace Venturi quencher to reduce pressure drop in scrubber • Tube-in-shell air heater to prevent leakage	• Identify the best operators (incentivize) ●●●●● • Optimize fan/pump redundancies—neural net ● • Primary air temperature optimization ● • Air/fuel balancing individual burners ● • Optimize control valve pressure loss ● • Optimize piping pressure loss • Recover vent-steam heat • Boiler heating surface adjustments • Optimization of electrostatic precipitators with emissions monitoring systems (EMS) • Belt scales/continuous ash monitors • Re-burn ash to extract additional energy • Optimize start-up sequence • Lower air heater output temperature by controlling SO_3 dew point • Improve water chemistry/management (for turbines) • Improve O_2 measurements in boiler • Optimize pressure on crossover line between the intermediate pressure (IP) and low pressure (LP) bypass • Improve top end instrumentation

● Highest impact on efficiency
▲ Most widely applicable across all plants

GROUP C

Technical Options to Improve the Thermal Efficiency of Existing PC Power Plants (2 of 2)

Sensors and Monitoring	Coal Management	Maintenance
• Real-time performance monitoring ●●●●● ▲▲ • Standardize performance metrics ●● ▲▲▲ • Cycle isolation—better value monitoring ● ▲ • Condenser monitoring ● • Detecting tube leaks ● • Air flow measurement for boilers • Thermocouples to identify leaking steam traps • Advanced fireball instrumentation	• Use low-grade heat for coal drying ●●●●●● • Understand fuel being burned ●● ▲ • Improve coal fineness ● • Keep coal piles dry (cover) • Prevent coal stagnation/degradation	• Perform maintenance to achieve needed heat rate improvement ● ▲ • Increase and incentivize frequency of maintenance ● ▲ • Increase frequency of boiler feed pump replacement or rebuild ●● • Air pre-heater modification/maintenance ●●

● Highest impact on efficiency
▲ Most widely applicable across all plants

GROUP C

Barriers and Challenges That Inhibit the Adoption and Application of Technical Options

Technical	Regulatory and Government	Operations Customs	Costs

• Age of fleet prevents significant changes ●●●●
• Inability to compare plants on same basis ●●●
• Difficult to measure heat rate ●
• Uncertainty in EMS—high reporting ●
• Plant efficiency is limited by its existing design ●
• Controversy over existing standards—ASME efficiency standards ●
• Negative effects of slagging
• Combustion optimization incomplete (particularly in real-time)
	• Uncertainty surrounding CO_2 price ●●●●●●●●
	• Uncertainty of new regulations ●●●●●●
	• Conflicting visions of DOE/EPA ●●●
	• Negative societal perception of coal ●●●
	  – Prevents new plant construction
	  – Uncertainty of plant longevity
	• Constant threat of NSR in response to changes ●
	• Inability to make long-term commitments—prevents coal drying technology ●
	• Availability reliability—forced to focus on reliability, not efficiency
		• Operator/management "culture" ●●●●●
		• Lack of management support for regular maintenance activity ●●●●●
		• Small staffing—difficult to implement/operate/ maintain new concepts ●●●●
		• Heat rate not recorded consistently in industry ●
		• Lack of training—monitor, operations
		• Insufficient technical personal on user side
		• Changing nature of electric load
			• Fuel cost pass through ●●●●●●
			• Lack of capital funding ●●●
			• Short-term vision to make financial decisions ●
			• Requirements for non-economic dispatch ●
			• Cost/benefit of improvements (may not pay off)
			• Cost of developing/testing advanced materials
			• Rate recovery—can't commit without it
			• Differential of energy cost to profit
			• High capital cost of coal drying
			• Uncertainty of fuel supply and prices
			• PRB costs—more efficient than Appalachian

● Most important

GROUP C

POTENTIAL INITIATIVES

- Incentives for existing fleet to implement upgrades/repairs ●●●●●●
  - Low cost loans for efficiency improvements
  - Tax credits, etc.
  - Federal fuel incentives
- Reach out to senior management—Secretary of Energy and CEOs level ●●●●
  - Highly visible efficiency award for top plants
  - Non-economic incentives
  - Decrease risk of stranded investment
- Technology demonstrations cost shared by DOE ●●●●
- Retire plants with heat rate above a certain level ●●●
  - Will require significant incentives, (minimum heat rate ~11,200 MMBtu/kWh)
- New regulations prevented from affecting existing plants for a time ●●
  - Specified time (5 years)
- Establish a price on CO_2 ●●
- Develop common standard for heat rate—rigorously analyze, agreed upon metric ●●
  - Requires partnership among utilities
- Identify and remove negative incentives ●
- Create a DOE/EPA working group—better communication ●
- Provide financial recovery while in construction ●
- Share best practices among managers/operators ●
- Streamline permitting process for high-efficiency plants
  - Couple with retirement of old plants
- DOE/utility working group
- Implement means to profit from fuel improvements
- Federal initiative for voluntary state participation—to allow rate recovery
- Minimum staffing requirement for certified engineers
- Maintenance initiatives
- Operational initiatives
- Required CO_2 /MWh or efficiency standards

● Most important

GROUP C
INITIATIVES (1 OF 4)

Technology Demonstrations	
Description and Key Features	
This initiative seeks to demonstrate and quantify the benefit of technologies that can increase efficiency. Successful implementation would require a team of experts to identify candidate technologies, determine metrics for assessment, and provide plants with both data and the opportunity to see the benefits of the technologies firsthand. Such a program not only boosts efficiency and benefits the plants, but may serve as the foundation for future investments in other plants. • Could be implemented through the development of a "model plant," or could be applied to several plants • Candidate technologies need to be selected • Requires a network of information sharing • Thermal efficiency improvements need to be accurately quantified • Choose a group of technologies • Prove their heat rate benefits • Quantify their benefits.	
Implementation Steps	
• Gather utility experts to identify the technologies we want to look at and how they work with each other (1 year) • Decide on metrics and parameters to assess the effect of implementing these technologies (1 year) • Test the technologies (2-3 years) • Create matrix of results (2-3 years)	
Roles for Government	**Roles for Industry/Others**
• Make funding/incentive available • Developing requirements for certification • Host annual conference	• Supply plants and bear the risk • Cost share
Estimated Impact (Metrics)	**Next Steps**
• Lays the foundation for future programs and company investments • Helps define the 36% goal with supporting information • Could help create a seal of approval for technologies	• Get DOE to buy in on concept • Create working group • DOE/EPA interface

GROUP C
INITIATIVES (2 OF 4)

<table>
<tr><th colspan="2">Reach out to Senior Management of Utilities</th></tr>
<tr><th colspan="2">Description and Key Features</th></tr>
<tr><td colspan="2">This initiative seeks to justify investment in heat-rate improvements to senior utility personnel through non-economic motivation. Successful implementation would require very high-level involvement at a government level to capture the attention of utility CEOs, a PR campaign, and the establishment of a highly visible award for efficiency improvements. Such a program could fuel competition among utilities and achieve broad efficiency increases nationwide.
• Requires DOE involvement at the highest level
• Refocuses CEO and plant manager priorities towards energy efficiency
• Requires a highly visible PR campaign</td></tr>
<tr><th colspan="2">Implementation Steps</th></tr>
<tr><td colspan="2">• Get support from Secretary of Energy to get CEOs on board (6 months)
• Create a PR campaign
• Create a top-10 plant reward/award program for energy efficiency improvements (6 months – 1-year)
• Define criteria (1-year)
• Give out 2011 awards</td></tr>
<tr><th>Roles for Government</th><th>Roles for Industry/Others</th></tr>
<tr><td>• Secretary of energy gets CEOs together
• Create PR campaign
• Create the program
• Define criteria</td><td>• Participation at the highest level
• Plan generation R&D managers communicate the importance of the effort to CEOs</td></tr>
<tr><th>Estimated Impact (Metrics)</th><th>Next Steps</th></tr>
<tr><td>• Reduce carbon emissions
• Reduce cost of electricity
• Bring awareness to efficiency
• Provide top down support to heat rate improvements</td><td>• Get five to six utilities to sign in and others will follow
• Create the program</td></tr>
</table>

Incentives for Existing Fleet to Implement Upgrades/Repairs

Description and Key Features

This initiative seeks to provide incentives for the existing coal-fired fleet to implement equipment upgrades and/or repairs. Successful implementation would require the identification of particular improvement opportunities and incentives to be granted, as well as a standard for the determination of efficiency. This program would be applicable to plants of all sizes and efficiencies, would allow utilities to quantify improvements implemented by both dollar and CO_2 value, and would put coal-fired plants on the path toward successful accommodation of carbon capture and storage.

- Broad based to include any type of plant
- Incentives for both currently efficient and inefficient plants, but more focused on inefficient ones (above 11,200 MMBtu/kWh)
- Incentives proportional to size of the plants, applicable for all kinds of equipment
- Potential incentives: Financial recovery; low interest funding; impunity from new regulations (with a minimum percentage increase in efficiency)
- New/Repaired units will displace other, low efficiency units
- Incentive to maintain efficiency at a particular level

Implementation Steps

- Form a joint government-industry task force (no more than six months) to:
  - Identify qualifying technologies
  - Identify the potential for gains
  - Identify the funding mechanism
  - Identify the magnitude of incentives necessary
  - Qualify incentives by level of efficiency increase
  - Determine metrics for performance (heat rate or CO_2 emissions)
  - Develop a standard for efficiency improvements
  - Bring data to OMB
- A fully implemented program must be realized in 3–5 years to reach the 2020 goal

Roles for Government	Roles for Industry/Others
• Bring about and participate in a joint government-industry task force • Examine existing incentives • Streamline the permitting process • Monitor program	• Participate in task force • Implement changes • Include environmental groups and NGOs

Estimated Impact (Metrics)	Next Steps
• Metrics for particular plants will be individualized • Rate of participation • Dollar value of participation • Dollar value of improvements made • Dollars invested/[CO_2 avoided/kWhr]	• Identify the right people for a task force (no more than three months) • Provide more depth/flesh out the program • Get utility participation • Create the task force

• Consumer dollars saved (COE) • Direct and indirect job effects • Follow up reporting and measurements to ensure long-lasting improvement	

GROUP C
INITIATIVES (4 OF 4)

Retire Plants with Heat Rate above a Certain Level

Description and Key Features

This initiative seeks to quantify a heat-rate level above which power plants would be encouraged to retire (11,200 MMBtu/kWh was suggested). Successful implementation would require the adoption of a standard method for determining heat rate and subsequent application, as well the identification and proffering of the incentive(s) to do so. Such a program would remove the plants with the lowest efficiency and provide plant managers with an alternative to running their plants into the ground.

- Fuel cost pass through serves to prevent retiring of old/inefficient plants
- May include gas plants
- May be necessary to tie-in replacement with a new coal plant (i.e., super critical/advanced turbine design)
- CCS may also serve as a tie-in—dependent on location (for sequestration)
- Shutdown cost share could be an incentive
- Retiring/Replacing just the boiler not feasible—too many ancillary considerations
- CO_2 emissions may also work as a metric for retirement—particularly annual rates

Implementation Steps

- Form a joint government-industry task force (no more than six months) to:
  - Identify qualifying technologies
  - Identify the potential for gains
  - Identify the funding mechanism
  - Identify the magnitude of incentives necessary
  - Qualify incentives by level of efficiency increase
  - Determine metrics for performance (heat rate or CO_2 emissions)
  - Develop a standard for efficiency improvements
  - Develop a ranking scheme for plants
  - Bring data to OMB
- A fully implemented program must be realized in 3–5 years to reach the 2020 goal

Roles for Government	Roles for Industry/Others
• Bring about and participate in a joint government-industry task force • Examine existing incentives • Streamline the permitting process • Monitor program • Don't ignore smaller utilities (smaller units often least efficient)	• Fully participate in task force • Involve smaller utilities • Provide opportunities for improvement • Include EEI

Estimated Impact (Metrics)	Next Steps
• Net reduction of CO_2 emissions • Number of plants retired • Jobs created/Economic impact • Avoided pollutants (NO_x, SO_x, etc.) • "Naturally" retired vs. opt ins (a tangible, public benefit) • Follow up reporting and measurement	• Identify the right people for a task force (no more than three months) • Provide more depth/flesh out the program • Get utility participation • Create the task force

Appendix A: Full Participant List

Scott Affelt	Zolo Technologies, Inc.
William Babiuch	Midwest Research Institute
Nicholas Bianco	World Resources Institute
Jon Blaney	ICF International
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Jared Ciferno	National Energy Technology Laboratory
Andrew Cotter	National Rural Electric Cooperative Association
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Tom Fogarty	PNT Energy
Terry Fujino	Mitsubishi Power Systems
Jon Gallinger	Alstom
Bob Giglio	Foster Wheeler Global Power Group
Ed Gonzales	Xcel Energy
David Hopkinson	U.S. Department of Energy
Yasunori Ishizu	Mitsubishi Heavy Industries, Ltd.
Stan Kaplan	Congressional Research Service
Lloyd Kelly	Leonardo Technologies, Inc.
Kenneth Kern	National Energy Technology Laboratory
Sikander Khan	U. S. Department of Energy
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Bill Krause	McKinsey & Company
Katrina Krulla	National Energy Technology Laboratory
Fred Lang	Exergetic Systems
Ed Levy	Lehigh University Energy Research Center
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George Mues	Ameren Corporation
Sastry Munukutla	Tennessee Technical University
Paul Myles	Worley Parsons Group, Inc.
Russell Noble	Southern Company
James Nyenhuis	Emerson Process Management
Karen Obenshain	Edison Electric Institute
Colin O' Brien	Natural Resources Defense Council
Sherry Odom	GE Energy
Karen Palmer	Resources for the Future
Gavin Pickenpaugh	National Energy Technology Laboratory
William Pott	Booz Allen Hamilton
Darlene Radcliffe	Duke Energy
Barry Rederstorff	American Electric Power
Judah Rose	ICF International
Pete Rozelle	U.S. Department of Energy
Donald E. Ryan	The Babcock & Wilcox Company
Bob Seay	Worley Parsons Group, Inc.
Scott Stallard	Black & Veatch

Jeff Stallings	Electric Power Research Institute
Joseph Strakey	National Energy Technology Laboratory
Bob Tramel	Tennessee Valley Authority
John Walke	Natural Resources Defense Council
James Wood	U.S. Department of Energy
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Facilitators

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